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NASA TECHNICAL TRANSLATION NASA TT F-15,290

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Translation of: "Ob odnom metode vosstanovleniya znacheniya kalibrovochnogo signala," Academy of Sciences of the USSR, Institute of Space Research, Report Pr-137, Moscow, 1973, 13 pp.

(NASA-TT-F-15290) ONE METHOD OF RESTORATION OF THE VALUE OF A CALIBRATION SIGNAL (Linquistic Systems, Inc., Cambridge, Mass.) 12 p HC $4.00 CSCL 14B G3/14

N74-19086

Unclas
32630

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MARCH 1974

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TT F-15,290		

4. Title and Subtitle
ONE METHOD OF RESTORATION OF THE VALUE OF A CALIBRATION SIGNAL

5. Report Date
March 1974

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address
LINGUISTIC SYSTEMS, INC.
116 AUSTIN STREET
CAMBRIDGE, MASSACHUSETTS 02139

11. Contract or Grant No.
NASW-2482

13. Type of Report & Period Covered
TRANSLATION

12. Sponsoring Agency Name and Address
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes
Translation of: "Ob odnom metode vosstanovleniya znacheniya kalibrovochnogo signala", Academy of Sciences of the USSR, Institute of Space Research, Report Pr-137, Moscow, 1973, 13 pp.

16. Abstract
The article discusses a method for restoration of the level of a calibration signal in an instrument whose value is beyond the measurement limits of the recording system. The restoration process employs recordings of transitional processes involved in switching the instrument from the measurement mode to the calibration modes. An experimental check showed that the accuracy of restoration of the calibration level was close to the measurement accuracy of the recording system.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	UNCLASSIFIED - UNLIMITED

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	12	4.00

ONE METHOD OF RESTORATION OF THE VALUE OF A CALIBRATION SIGNAL

N. N. Krupenio, V. A. Ladygin, N. Ya. Shapirovskaya

Telemetric systems with quantization of amplitude and time /3*
are usually employed for the transmission of the information which has been received in the course of remote measurements of physical parameters using electrical methods. Quantization with respect to amplitude is used for conversion of an analog output signal from an instrument into digital form. Quantization with respect to time arises from the need for transmitting a number of measured parameters over a single communication channel. A specific periodicity for information reception is thereby developed.

We shall discuss a case in which the periodicity of information collection T is somewhat higher than the time constant of the instrument t and much higher than the rate of variation of the measured parameter $\frac{dP}{dt}$. This relationship is satisfied in a number of systems for remote measurement and is employed for automatic averaging of measured parameters by means of a computer. In this connection, the system develops a certain amount of excess information but it is used for increasing the accuracy of the experiment.

In order to carry out remote measurements (of temperature, for example), the measuring device usually is subjected to preliminary calibration to establish a relationship between the output voltage of the instrument U and the measured parameter P. However, this relationship can change with time for a number /4

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*Numbers in right-hand margin indicate pagination in foreign text.

of reasons. Therefore, in order to increase measurement accuracy, calibration signals are fed into the instrument from standard or reference points. If the characteristic of the instrument P = f(u) is linear, two calibration points will be quite sufficient, located at the beginning and end of the instrument scale. (They completely characterize the "zero" position of the instrument and the curvature of its characteristic curve.) Input of the calibration signals can be accomplished in various ways. In our instrument, we used calibration signal input systems with time division of the calibration and measurement modes (see Figure 1).

In the course of the experiment, there is a periodic switching of the instruments from the measurement mode to the calibration mode ($U_{cal\,1}$ and $U_{cal\,2}$). One such arrangement is shown in Figure 2. In our instrument, there was a downward shift of the output characteristic of the instrument, causing a shift of the first calibration level $U_{cal\,1}$ below the "zero" of the telemetry. The existence of a time constant for the instrument (T), greater than the information reception period (T), causes the development of a transitional process at the telemetry output which is described by several points. Information on transitional processes is employed by us for restoring the $U_{cal\,1}$ level.

Figure 2 shows two forms of transitional processes:

First--discharge of a capacitor when the instrument is switched from the measurement mode to the calibration mode I ($U_{cal\,1}$).

Second--discharge of a capacitor when switching the instrument from calibration mode 2 to the measurement mode. Both types /5 of transitional processes involve primarily the discharge of the same capacitor in the output filter of the instrument, i.e., they obey the same law. The second type of transitional process "calibration 2→ measurement mode" is represented completely in telemetric notation, while in the first form there are only a small number of initial points, inasmuch as the others lie below the level of "zero" telemetry. The voltage value up to which the discharge of the capacitor takes place in the first type of transitional process is the desired value of the calibration level ($U_{cal\,1}$).

If we know the law of the variation of the transitional process and several voltage values at the beginning of the process, we can find $U_{cal\,1}$. However, the law of the discharge of the capacitor of the output filter is not purely exponential and cannot be calibrated prior to measurements inasmuch as the parameters with the capacitor can change with time.

We use the following method of calculating $U_{cal\,1}$:

1. $\mathring{U}(t) = \mathring{U}_{final} + (\mathring{U}_{initial} - \mathring{U}_{final})\ \mathring{f}(t)$ (1)

where $\mathring{U}(t)$ is the true voltage at the moment of the discharge, $\mathring{U}_{initial}$ is the voltage at which the discharge of the capacitor begins (at a moment in time t = 0),

$\mathring{U}_{final}$ is the voltage up to which the capacitor discharges.

A hypothesis has been put forward which holds that $\mathring{f}(t)$ is independent of the values $\mathring{U}_{final}$ and $\mathring{U}_{initial}$. For both transitional processes, equation (1) can be rewritten as follows: /6

$\mathring{U}(t) = \mathring{U}_{cal\,1} + (\mathring{U}_{meas} - \mathring{U}_{cal\,1})\ \mathring{f}(t)$ for the first type

$\mathring{U}(t) = \mathring{U}_{meas} + (\mathring{U}_{cal\,2} - \mathring{U}_{meas})\ \mathring{f}(t)$ for the second type where U_{meas} is the actual voltage corresponding to the physical characteristic of the measured parameter (for example, for the temperature).

2. We will show, using the example of the transitional process of the second type, that the transitional process corresponds to the suggested hypothesis. During the entire period of remote observations, we conducted six measurement sessions,

in each of which we measured five calibrations of the second type (a total of 30 calibrations in all), making it possible to perform a statistical analysis of this information.

Let us assume initially that quantization is absent and, instead of a real telemetric signal, we have a function $U(t)$ obtained by superimposing the noises of the telemetric system $\xi(t)$ on the actual voltage $\overset{\circ}{U}(t)$:

$$U(t) = \overset{\circ}{U}(t) + \xi(t) \tag{4a}$$

$$U_{meas} = \overset{\circ}{U}_{meas} + \xi_1(t) \tag{4b}$$

$$U_{cal\ 2} = \overset{\circ}{U}_{cal\ 2} + \xi_2(t) \tag{4c}$$

We will also assume that for any two moments in time t_1 and t_2 errors obtained by virtue of noises $\xi(t_1)$ and $\xi(t_2)$ are independent and have normal distribution with the same scatter σ_ξ^2. Let us establish the time t. We will examine the random value

$$f(t) = \frac{U(t) - U_{meas}}{U_{cal\ 2} - U_{meas}} \tag{5}$$

Here, $f(t)$ is distributed almost normally with a mathematical expectation $\overset{\circ}{f}(t)$ and dispersion σ_η^2 /7

$$\sigma_\eta^2 = \sigma_\xi^2 \frac{[1 + [1 - \overset{\circ}{f}(t)]^2 + \overset{\circ}{f}(t)^2]}{(U_{cal\ 2} - U_{meas})} \tag{6}$$

Formula (6) was obtained from the following considerations:

$$f(t) = \overset{\circ}{f}(t) + \eta \tag{7}$$

Following a number of transformations from equations (2), (3), (4) (5) we will have

$$\eta = \frac{\xi(t) - [1 - \mathring{f}(t)]\xi_1 - \mathring{f}(t)^2 \xi_2}{U_{cal\,2} - U_{meas}} \tag{8}$$

where of any two realizations $U(t)$ and $\tilde{U}(t)$ of the transitional process, the corresponding difference $(f(t) - \tilde{f}(t))$ is normally distributed with a scatter $\sigma_\eta^2 + \sigma_{\tilde{\eta}}^2$. Therefore with a probability $P > 0.997$, the following evaluation is valid:

$$|f(t) - \tilde{f}(t)| \leq 3\sqrt{\sigma_\eta^2 + \sigma_{\tilde{\eta}}^2} \tag{9}$$

inasmuch as $f(t)$ and $\tilde{f}(t)$ are independent and $\mathring{f}(t)$ is independent of the realization of the transitional process $[f(t) = \tilde{f}(t)]$.

The telemetric voltage is obtained as a result of the rounded-off values $U(t)$ up to similar whole values. Therefore, by replacing $U(t)$ by the telemetric voltage, we will make the error to be no more than one-half of a telemetric unit (TME). Consequently, if at a moment in time t the condition $U_{cal\,1} - U_{meas} \gg 1$ TME is fulfilled, in formula (5) we can disregard the influence of the telemetry error and calculate the value $f'(t)$. Then inequality (9) will make it possible to check the correctness of the hypothesis for the second type of transitional process and to calculate the permissible values of $U_{cal\,1}$ for the first type of transitional process. Let us rewrite inequality (9) in the inverted form:

$$|f(t) - \tilde{f}(t)| \leq 3\sigma_\xi \sqrt{\frac{2 - 2\mathring{f}(t) + 2\mathring{f}(t)^2}{(U_{cal\,2} - U_{meas})^2} + \frac{2 - 2\mathring{f}(t) + 2\mathring{f}(t)^2}{(\tilde{U}_{cal\,2} - \tilde{U}_{meas})^2}} \tag{10}$$

In order to be sure of the correctness of inequality (10), /8
we must know σ_ξ and $\overset{\circ}{f}(t)$.

In the ordinary telemetric system, the value σ_ξ is equal to 0.5 TME. In our case, it was possible to specify σ_ξ further experimentally. Using the service information channel of the instrument, we transmitted the values of calibration constant voltages. Each voltage value was repeated 20 times in the course of one cycle. There was a total of 30 cycles. The changes which were observed in the output of the telemetry at the level of each calibration voltage are determined only by the errors in quantization and the noises in the system ξ. Processing of the data from the recording of the values of the calibration voltages yielded σ_ξ equal to or less than one-third.

The value of $\overset{\circ}{f}(t)$ is determined as follows. Using all of the available realizations of the transitional process of the second type, formula (5) was used to determine $\overset{\circ}{f}(1)$, f(2), f(3), for moments in time separated from the beginning of the transitional process (t = 0), by t = 1T, 2T, 3T. For all the realizations, the average values $\overline{f(1)}$, $\overline{f(2)}$, $\overline{f(3)}$ were calculated and the non-mixed estimates of the scatter

$$\mathcal{D}_{f(t)} = \frac{\sum^{N} [f(t) - \overline{f(t)}]^2}{N-1} \qquad (11)$$

where N is the number of realizations.

As a result of calculations using formulas 5 and 11, we obtain the following:

f(1) = 0.598	$\mathcal{D}_{f(1)} = 580.10^{-6}$	$\sigma_{f(1)} = 0.0225$ /9
f(2) = 0.351	$\mathcal{D}_{f(2)} = 417.10^{-6}$	$\sigma_{f(2)} = 0.0204$
f(3) = 0.205	$\mathcal{D}_{f(3)} = 564.10^{-6}$	$\sigma_{f(3)} = 0.0238$

asmuch as $\sigma_{f(t)}$ was calculated from the conditions of maximum scatter, we can consider that its value determines the total scatter $\overset{\circ}{f}(t)$. Then the desired value $\overset{\circ}{f}(t)$ for the corresponding moments in time will lie in the following intervals:

$$\overset{\circ}{f}(1) = 0.598 \pm 0.023$$

$$\overset{\circ}{f}(2) = 0.351 \pm 0.020$$

$$\overset{\circ}{f}(3) = 0.205 \pm 0.024 \qquad (12)$$

Let us analyze inequality (10). The left-hand part of the inequality is determined on the basis of (5), and the right-hand side by the substitution of the calculated values $\overset{\circ}{f}(t)$ and σ_{ξ} for various realizations at corresponding moments in time. As a result of the calculation we find that the inequality is preserved for all existing realizations.

Hence, it has been shown that the suggested hypothesis is valid for all available realizations of total transitions of second type processes.

III. The level $U_{cal\,1}$ is determined on the basis of a known form and the initial points of the transitional process. Determination of the desired level is carried out using the selection method.

From the rough determinations of the level of $U_{cal\,1}$ with application of the data from laboratory calibrations, we know that $U_{cal\,1}$ lies within the limits -7 to -17 TME. If we substitute into formula (5) the values of $U_{cal\,1}$ = -7, -8 ... -17 TME, we can calculate f(1), f(2), f(3). The values of $U_{cal\,1}$ at /10
which the value f(t) falls into the corresponding interval (12):

$$0.575 < f(1) < 0.621$$
$$0.331 < f(2) < 0.371$$
$$0.181 < f(3) < 0.229$$

is the desired value. Examples of the results of these calculations of the value of $U_{cal\,1}$ are listed in the table below.

Number of calibration	$U_{cal\,1}$ TME	$\overline{U_{cal\,1}}$ TME	$\Delta U_{cal\,1}$ TME
1	-10 to -12	-11	± 1
2	-10 to -12	-11	± 1
3	- 9 to -11	-10	± 1
4	-10 to -11	-10.5	± 0.5
5	- 9 to -11	-10	± 1
6	- 9 to -11	-10	± 1
7	- 9 to -11	-10	± 1
8	- 9 to -11	-10	± 1
9	-10 to -12	-11	± 1
10	-11	-11	0

Averaging over all of the calibrations (30), $U_{cal\,1}$ will be equal to $\overline{U_{cal\,1}} = -10 \pm 1$ [TME].

Hence, this method of restoration of the level of calibration gives an accuracy which is close to that of the measurement of the telemetric system. +11

/12

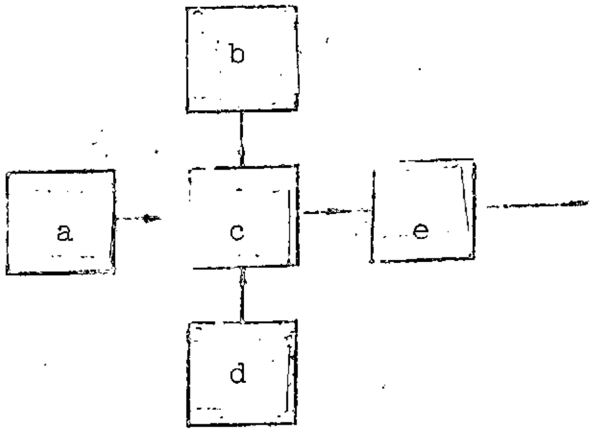

Fig. 1. Block diagram of the instrument; a--sensor; b--calibration electrical signal $U_{cal\,1}$; c--switch; d--calibration electrical signal $U_{cal\,2}$; e--electronic block; f--to telemetry system.

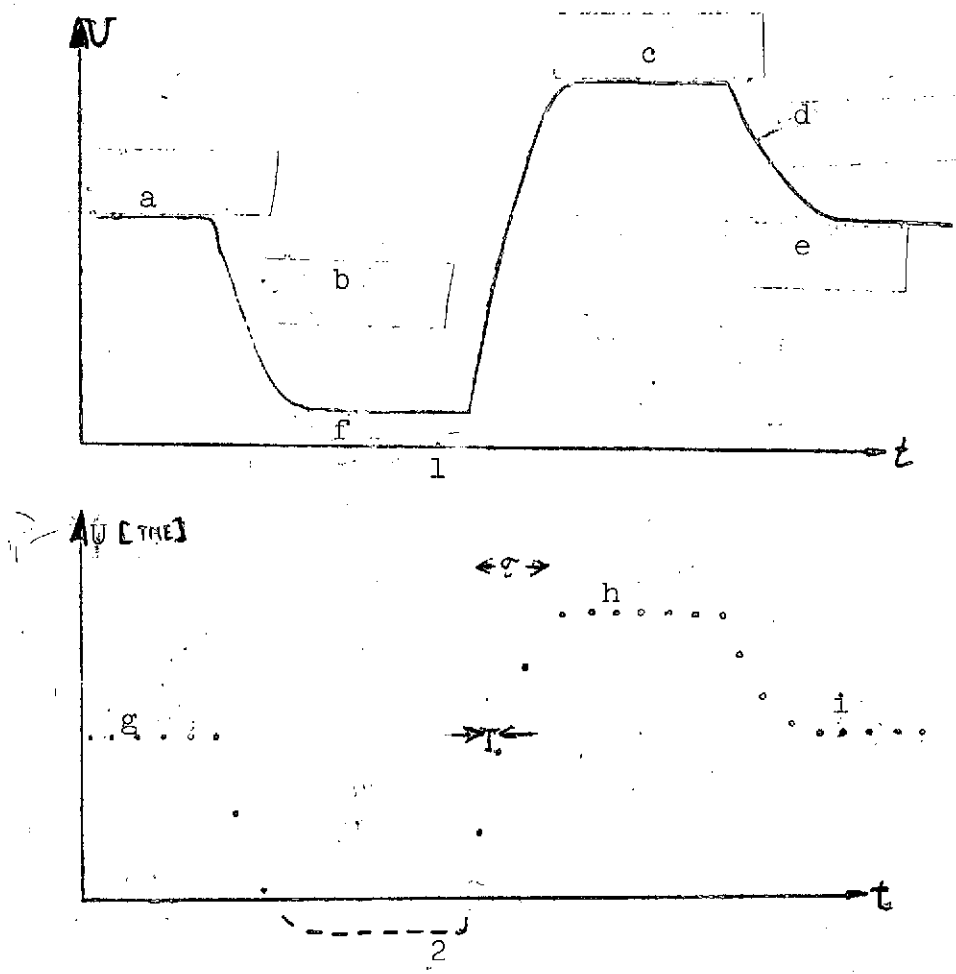

Fig. 2. Shape of the signal at the output of the instrument and telemetry system.

1. Signal at the output of the instrument
2. signal at the output of the telemetry

a--V_{meas}($V_{initial}$); b--first type of transitional process; c--$U_{cal\ 2}$ ($U_{initial}$); d--second type of transitional process; e--V_{meas} (V_{final}). f-$U_{cal\ 1}$ (U_{final}); g--U_{meas}; h--$U_{cal\ 2}$; i--U_{meas}.